A New 1.5 TeV LHC Injector

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OUTLINE

- Motivation for a 2nd ring.
- Injector Design Concept & Constraints.

Henryk Piekarz, Steve Hayes, and V. Kashikhin.

- LER Lattice Design:

  Arcs & Dispersion Suppressers

  Main Ring Magnets

  Arc & DS Optics

  J.A.J

  IR1/5 High Luminosity Straights

  Beam Transfer Options (2)

  Fast Pulsed Magnets

  Optics Option #1

  Optics Option #2

- Further Studies

Motivation for a Low Energy Ring

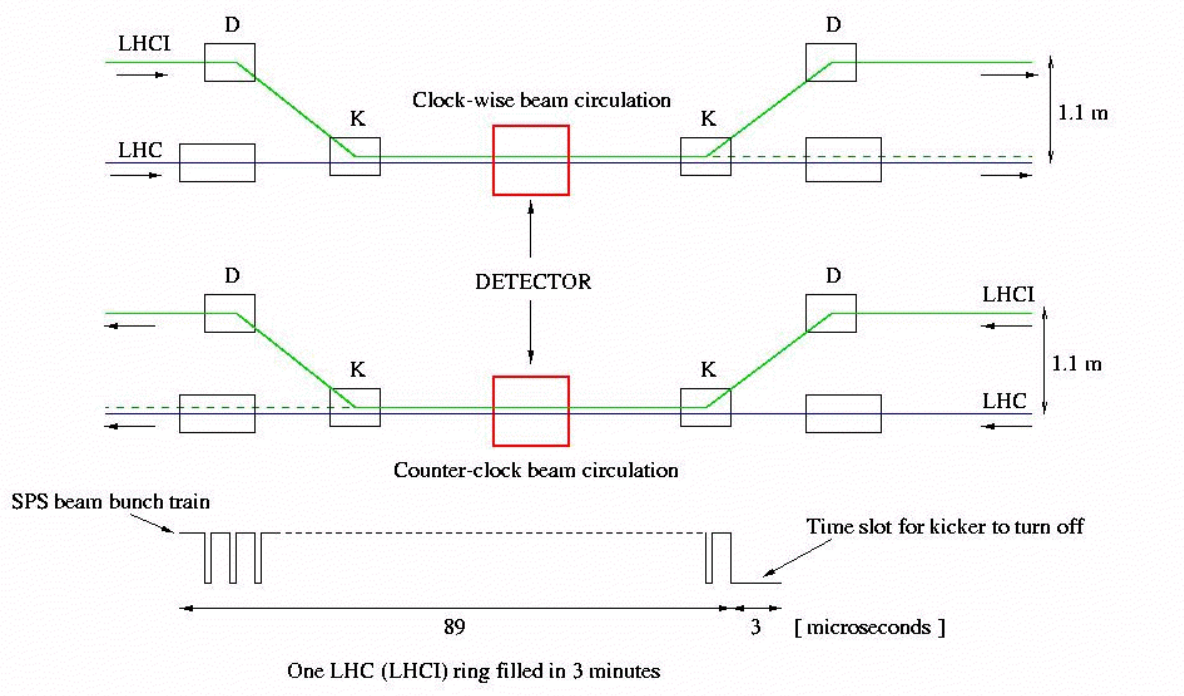
- The LHC magnets are reputed to have unsatisfactory field quality due to the large sextupole at the 450 GeV SPS injection energy.
- Possible solutions are: (a) build a new SPS ring to boost the energy to 1 TeV or higher, or;
  (b) build a new injector within the LHC tunnel to accelerate the 450 GeV beams to 1.5 TeV for transfer to the LHC.
- Advantages to option (b) [originally suggested by Lucio Rossi of CERN (9/05) & subsequently pursued by Henryk Piekarz] are:

  (i) the ring would be installed during scheduled LHC downtime — no HEP interruptions, and;

  (ii) with little, or no civil construction the price is reasonably cheap — ~$150 million (less than the Fermilab Main Injector, for example).

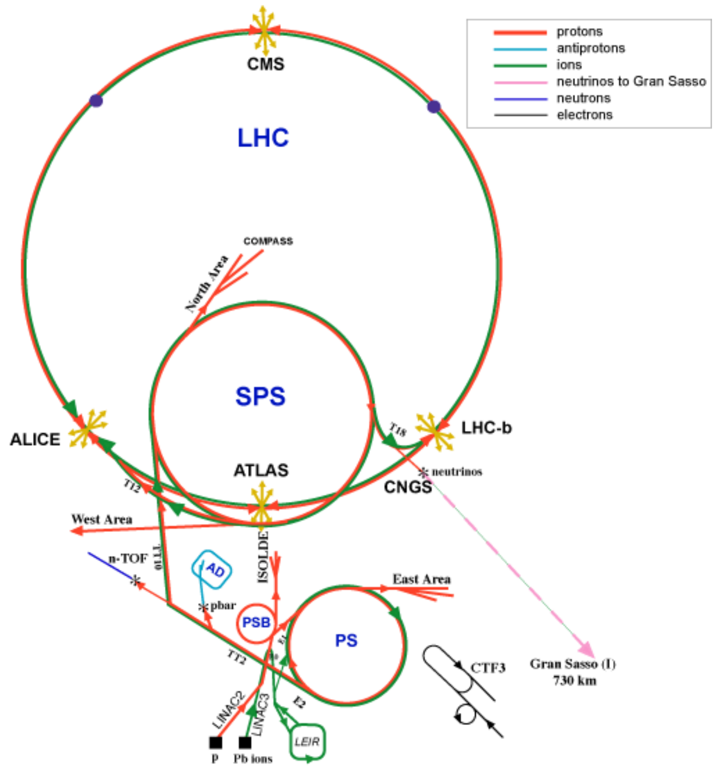
DESIGN CONCEPT & CONSTRAINTS

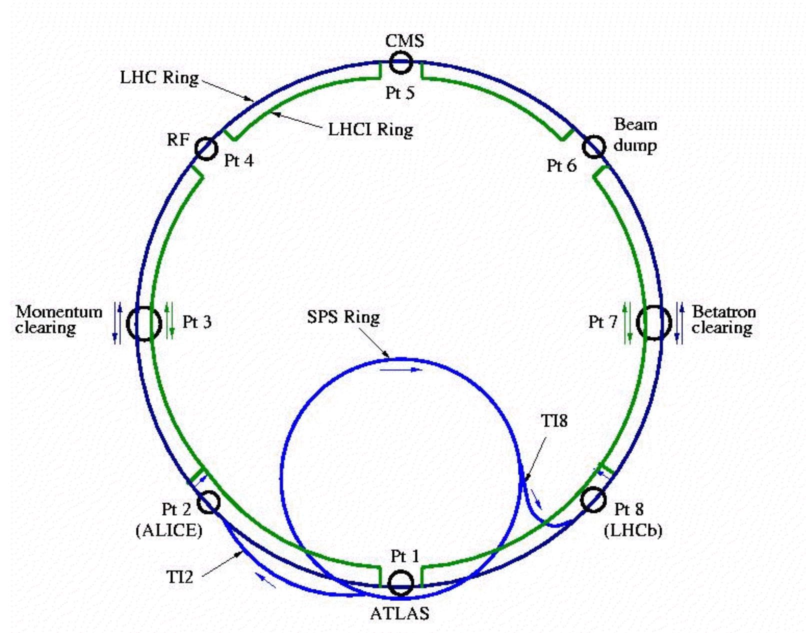
- The LER would be installed above the LHC in the LHC tunnel without major modifications ⇒ at a minimum the LER & LHC must share common beampipes through the detectors at IR1 & IR5 (Atlas & CMS) for this scheme to succeed.



- The magnet strings common to LER & LHC must be able to turn on/off in 3 μsec (the separation between the head & tail of the bunch train).

LER IN THE LHC COMPLEX





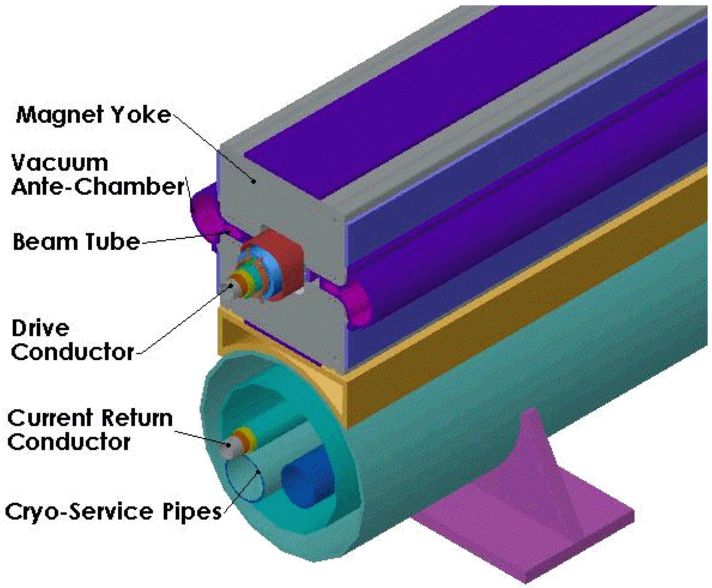
- Injection would continue to occur at IR's 2 & 8, with immediate transfer to the LER for acceleration to 1.5 TeV (details need to be worked out).

- Momentum & betatron scraping at IR's 3 & 7 can not be used by the LER.
- It is *hoped* that the RF at IR4 can be used (but seems unlikely at this time).
- It is *hoped* that the dump at IR6 can be used (still needs to be looked at).
- *Alice* & *LHCb* are unknown factors.

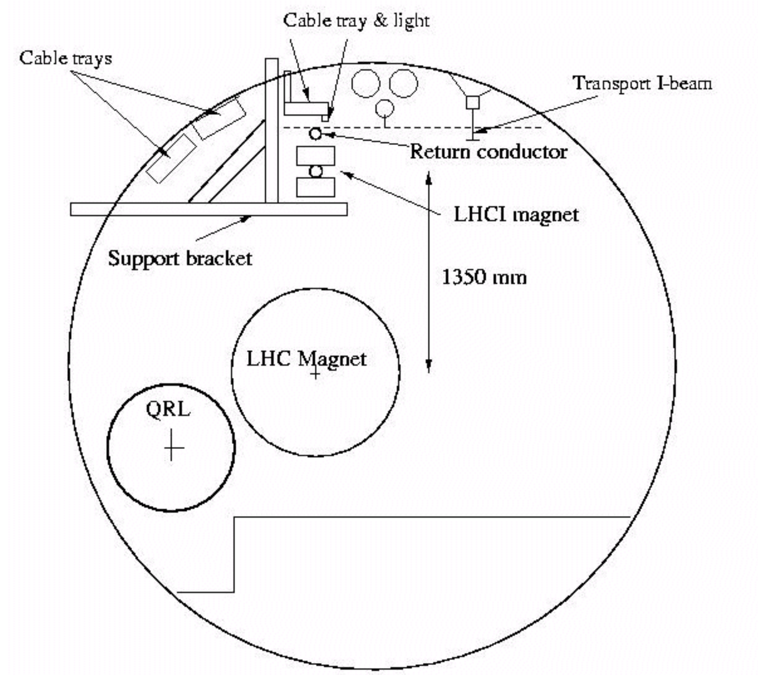
LER LATTICE - ARCS & DISPERSION SUPPRESSERS

Arc & DS Magnets:

- VLHC gradient magnets proposed for arcs & dispersion suppressers.



- Small (26 x 24 cm) physical cross-section, with 20 mm magnet pole gap.
- 1.6 T field at 55 kA.



- The LER ring fits easily above the LHC magnets.
- Vertical separation between the LER - LHC beams will be 1350 mm.

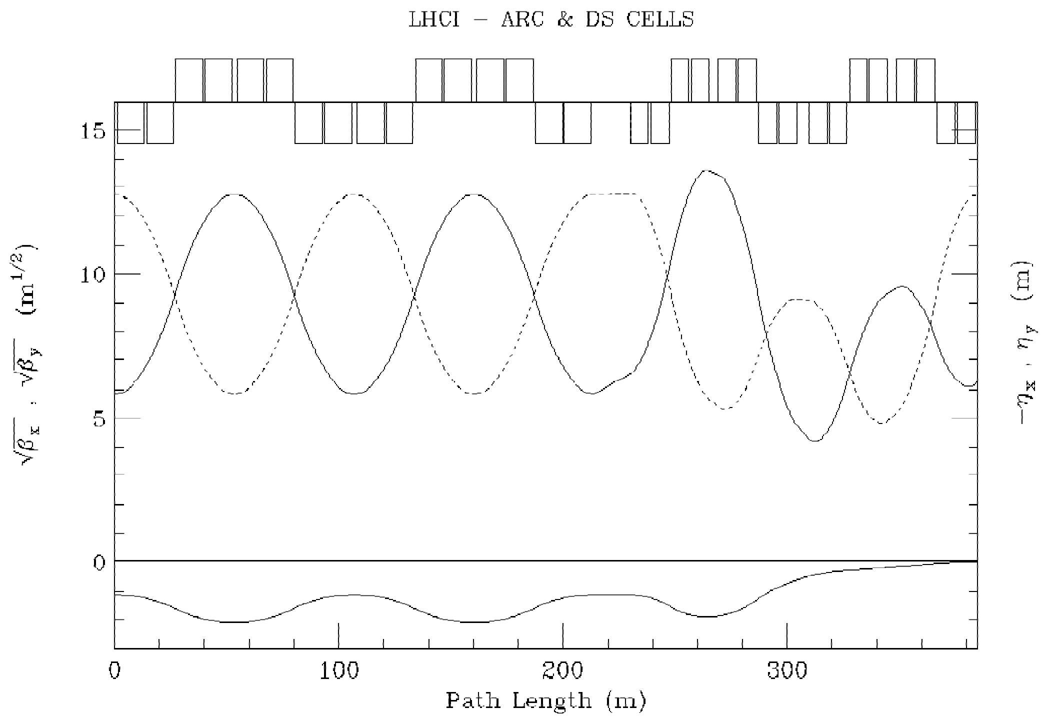
LER Arcs & Suppressers (cont'd)

Arc & DS Lattice Optics:

- Constructed from combined function 'transmission line' magnets to replicate LHC optics & match the LHC footprint.
- Dispersion suppressers are (almost) the same optical scheme as employed by the Main Injector — $^{2}/_{3}$ the bend & $^{3}/_{4}$ the length of arc cells.

Cell Type	Cell Length (m)	Magnet Types	L_{mag} (m)	# / Cell	B (T)	B' (T/m)
Arc	107	GF / GD	12	8	1.595	4.858
Suppressor	80	GSF / GSD	8	8	1.595	10.112

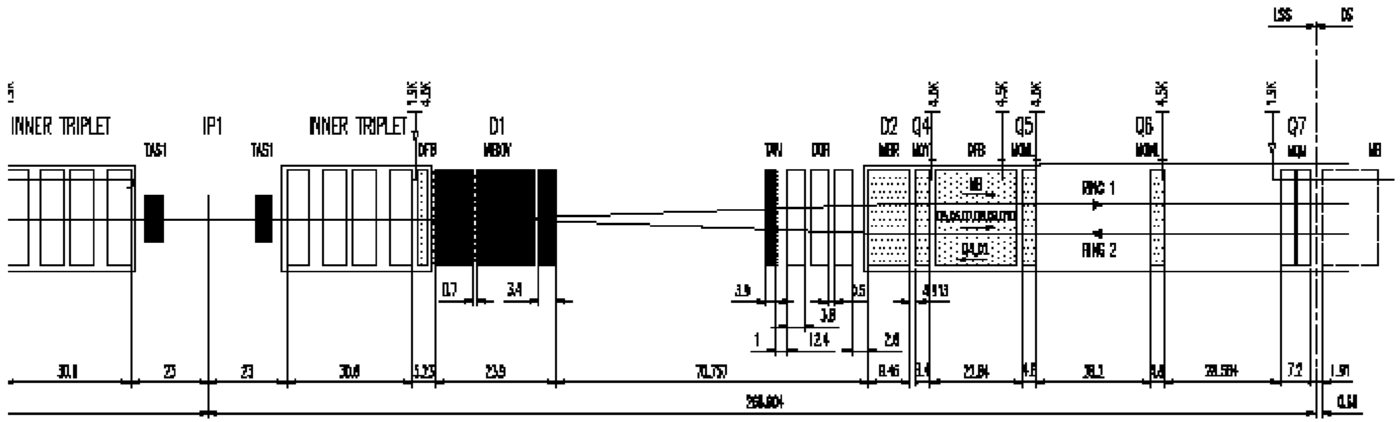
LER Arcs & Suppressers (cont'd)



- β (max) = 162 m (slightly less than in the LHC)
- η (max) = 2.10 m
- Phase advance / cell = 90^o

- In duplicating the LHC footprint, the gradient magnet focusing centers align with the bend centers. This creates an imperfect β match across the dispersion suppressers because the LHC bend centers are irregularly spaced.
- Arc & DS cells account for 22.4 km of the LER 26.7 km circumference.

LER LATTICE - HIGH LUMINOSITY IR1 & IR5 INSERTS



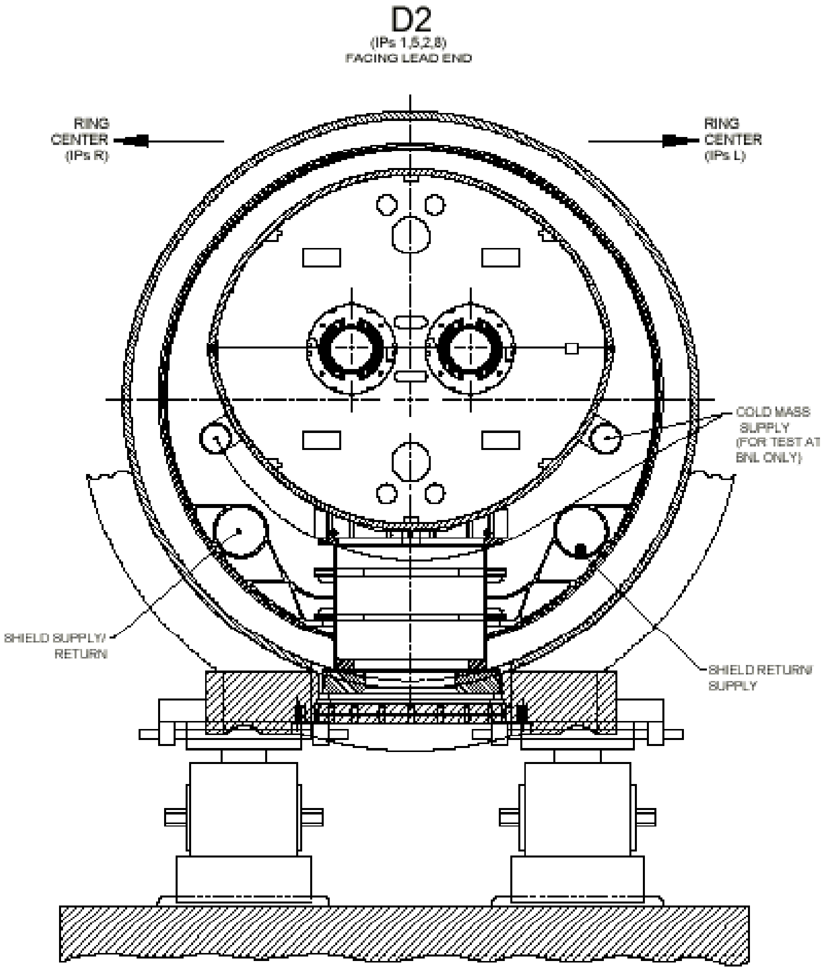
- Two potential schemes for separating the LER - LHC beams are being explored:

  (i) Instigate vertical separation of the LER from the LHC as close as possible to D1 to clear the D2 separation dipole 71m downstream. Preliminary magnet designs suggested the beams would be sufficiently separated to insert fast magnets 11m from the face of D1;

  (ii) Create additional horizontal separation of the beams originating at the inboard end of the D1 magnets and install vertical bends immediately at the exit of D1. This approach would require the D1's to shift towards D2 by ~6m to create space for the pulsed magnets.

Both approaches have implementation difficulties that will need to be addressed.

LER LATTICE - IR1/5 TRANSFERS (CONT'D)

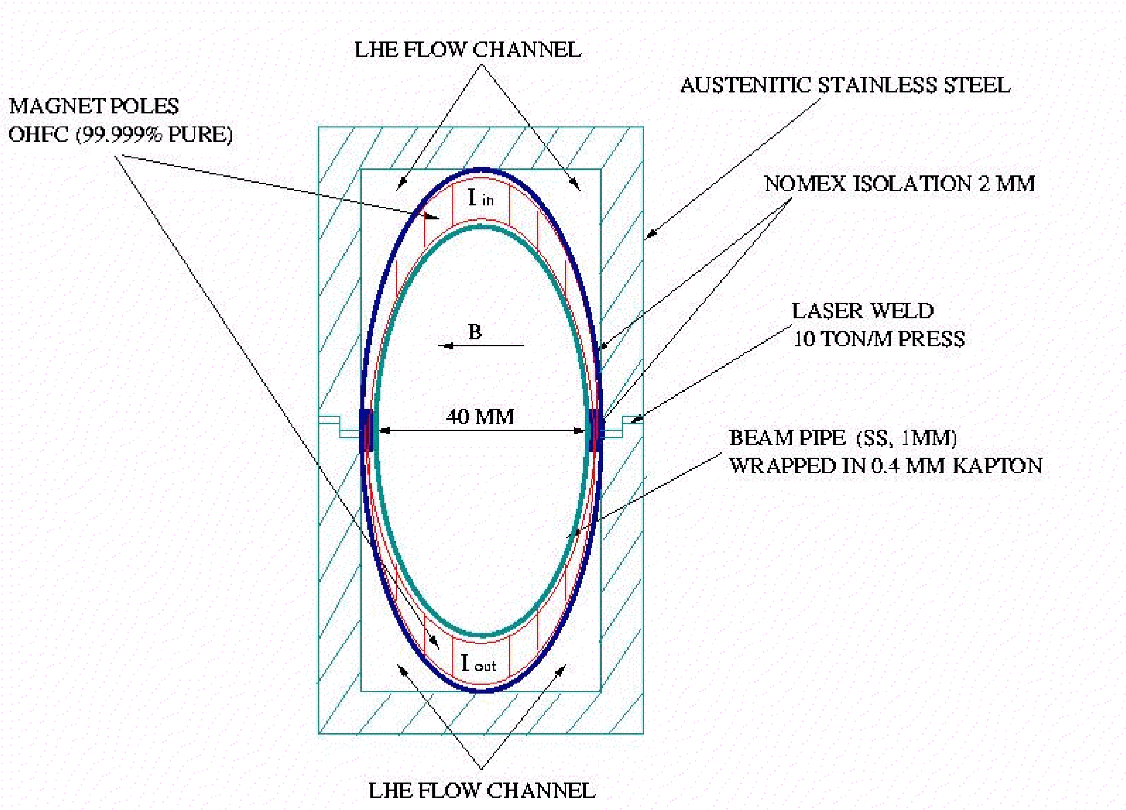


D2 Separation Dipole

- LHC magnets are massive -- the beams must rise a minimum of ~480 mm before the LHCI beampipe will clear the D2 (& downstream quadrupoles) cryostat.
- To install quadrupoles in the transfer line above the LHC magnets this elevation change must be significantly more.

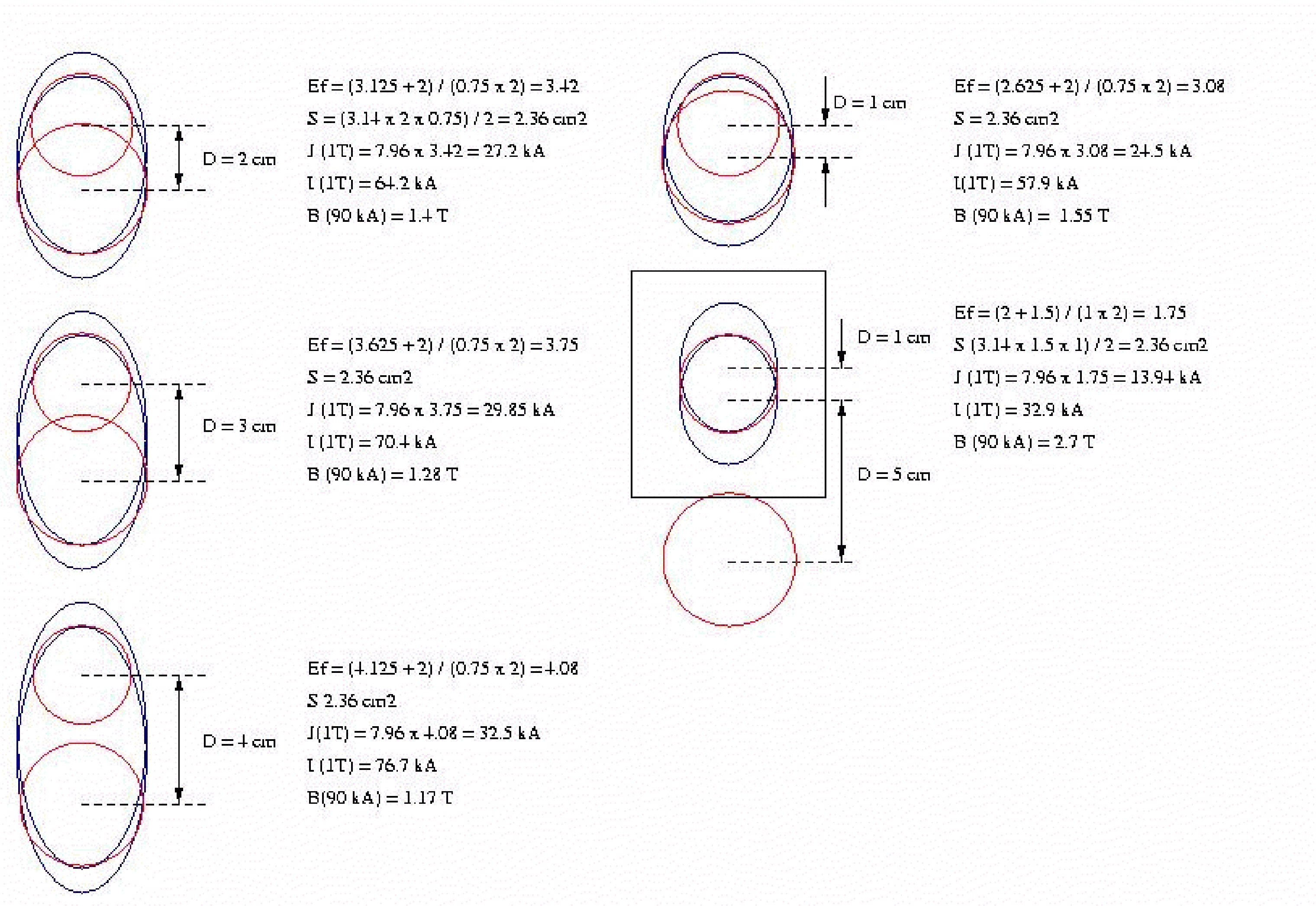
Fast Transfer Magnets:

- Transfering the beam from the LER to HC requires pulsed magnets able to turn on/off in 3 μsec (the separation between the head & tail of the bunch train).



|—— 65mm ——| .

Pulsed Vertical Bends with 4,5 & 6 cm gaps:



LER IR1 & IR5 MAGNETS (CONT'D)

LHCI-LHC Transfer Line Magnet Count

	B [T]	Magnet length [m]	Number of magnets	Drift space [m]	Total Magnet length [m]	Vertical shift [cm]	Total vertical shift [cm]	Beam path [m]	Magnet type
First Bend									
	1.55	0.8	2	0.2	1.8	1	1	1.8	Fast/Normal
	1.40	0.8	2	0.2	1.8	1	2	3.6	"
	1.28	0.7	3	0.3	3.0	1	3	6.6	"
	1.17	0.7	3	0.3	3.0	1	4	9.6	"
				2.4		1	5	12.0	
	LHC-LHCI beam pipe separation								
	2.7	0.9	8	0.8	8.8	7	12	20.8	Slow/Normal
				2.0		2	14	22.7	
	6.0	0.8	10	1.0	9.0	19	33	31.7	Slow/SC
				0.8		1	34	32.5	
Second Bend									
	6.0	0.8	18	1.8	16.2	34	68	48.7	Slow/SC
	LHCI beam passes over the face of D2								
Third Bend									
	6.0	0.8	18	1.8	16.2	34	102	64.9	Slow/SC
				1.0				65.9	
Fourth Bend									
	6.0	0.8	18	1.8	16.2	34	136	82.1	Slow/SC
				1.0				83.1	
	LHCI beam passes over the face of Q5								

All magnets are 2 bore types   Total number of magnet assemblies: 6

* Table prepared by Henryk Piekarz

LER IR1/5 TRANSFER OPTION #1

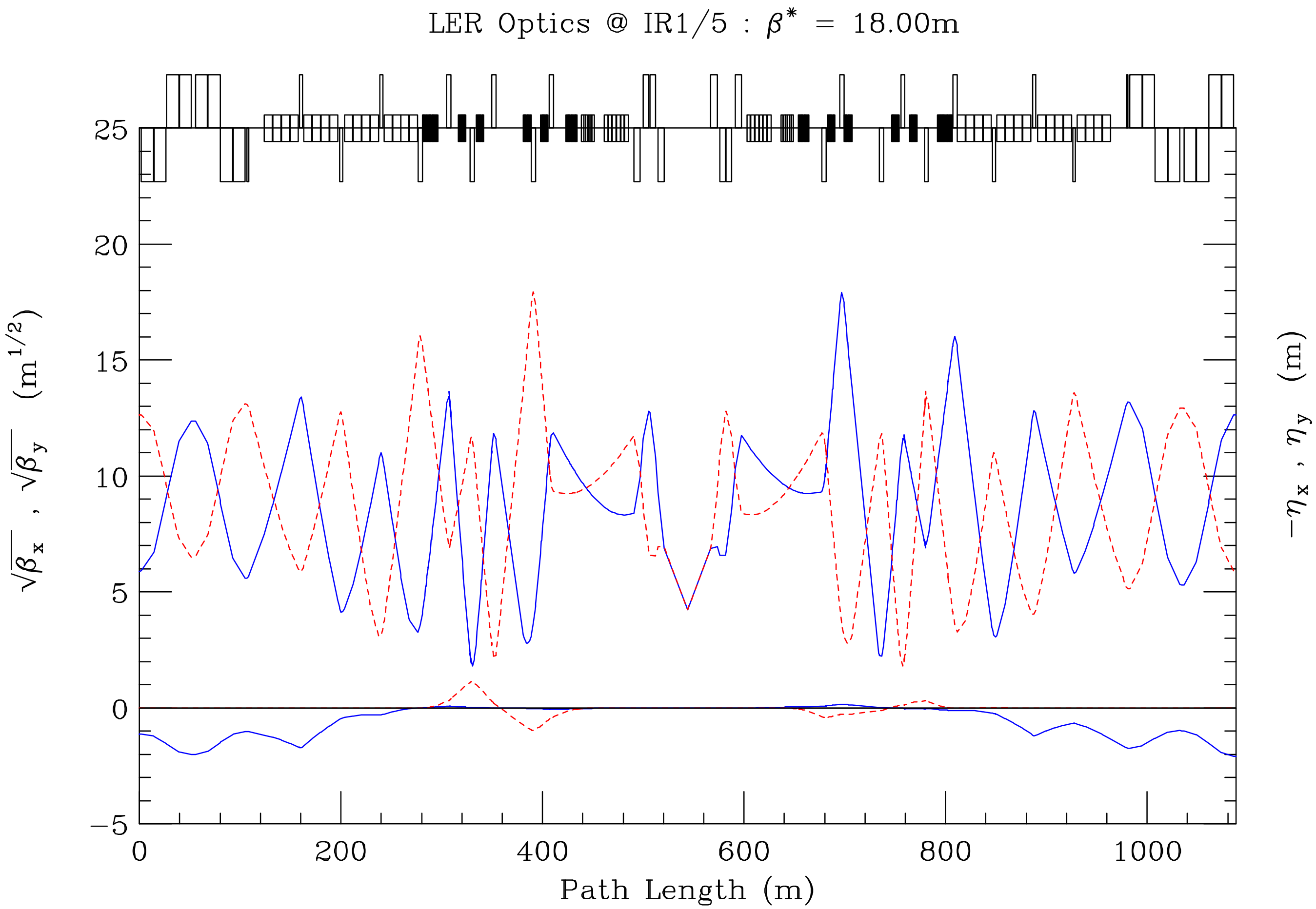
Vertical Bends:

- The elevation change to 1.35 m is accomplished in 2 steps — first to 0.675 m above the LHC beam center to clear D2 & the LHC quads, and then another rise to flatten out at 1.35 m by the end of the straight section.
- The initial bending is performed with pulsed magnets of appropriate apertures operating near 90 kA. Once the beams are well separated vertically the first 'up' bend is completed using a combination of 0.9m 2.7 T normal conducting magnets, and 6T 0.8m SC magnets. The remaining 3 bend centers all use 6.0 T SC magnets.

Matching quadrupoles:

- Quadrupoles in the straight section are powered anti-symmetrically in pairs.
- At IR1 & 5 the dispersion suppressers are constructed from separated function dipoles and quadrupoles. The quadrupoles are powered individually and, approximately, anti-symmetrically.
- Optics of the LER are matched to the LHC injection β^*'s of 18m at the IP, with $\beta(\max)$ = 320 m in the straight (comparable to LHC injection optics).

IR1/5 OPTION #1 - OPTICS



The vertical bends are performed achromatically so vertical dispersion & it's slope η* & η'* are also ≡ 0 at the IP.

IR1/5 OPTION #1 (CONT'D)

Matching Quadrupole Parameters:†

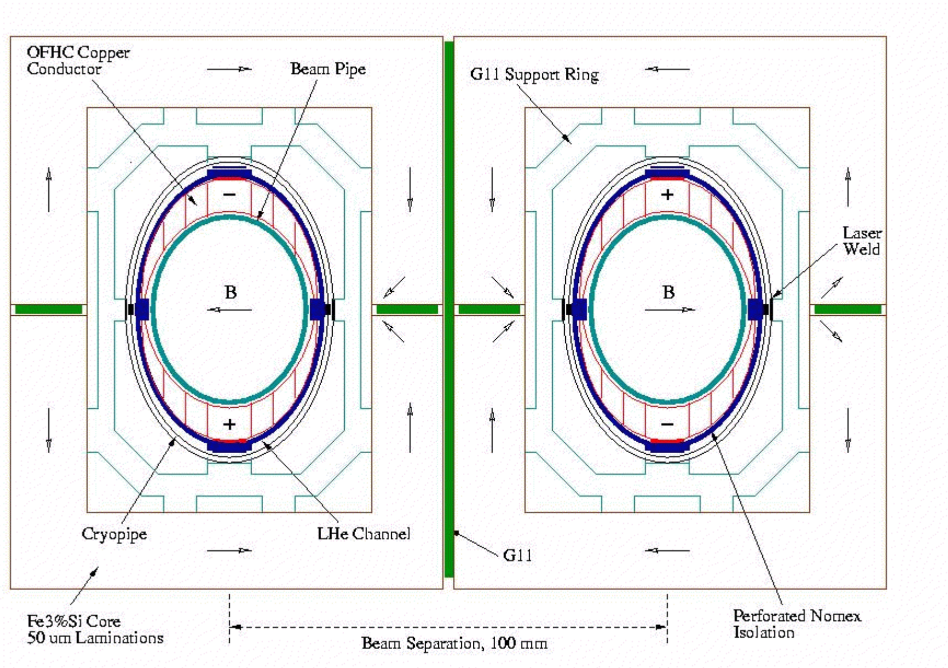
Quad	L (mag) (m)	B' (left) (T/m)	B' (right) (T/m)
Q4	4.0	-62.92	62.92
Q5	4.0	68.98	-68.98
Q6	4.0	-97.83	97.83
Q7	4.0	80.88	-80.88
Q8	4.0	-91.25	91.25
Q9	4.0	56.46	-56.46
Q10	3.0	-81.27	80.62
Q11	3.0	68.45	-68.24
Q12	3.0	-58.38	56.39
Q13	1.5	48.02	-39.53

† Even preliminary quad designs do not yet exist -- lengths & gradients will be adjusted as necessary.

IR1/5 OPTION #1 (CONT'D)

Recent Developments with Option #1:

- Magnet designers have determined that to ensure good field quality the initial fast magnets must be laminated. This results in separating the beams horizontally by 100 mm before vertical bending can commence.
- Instead of magnets installed 11m from D1, the distance now becomes ~33m (nearly half way to D2), which is much, much too late to clear the D2 dipole.

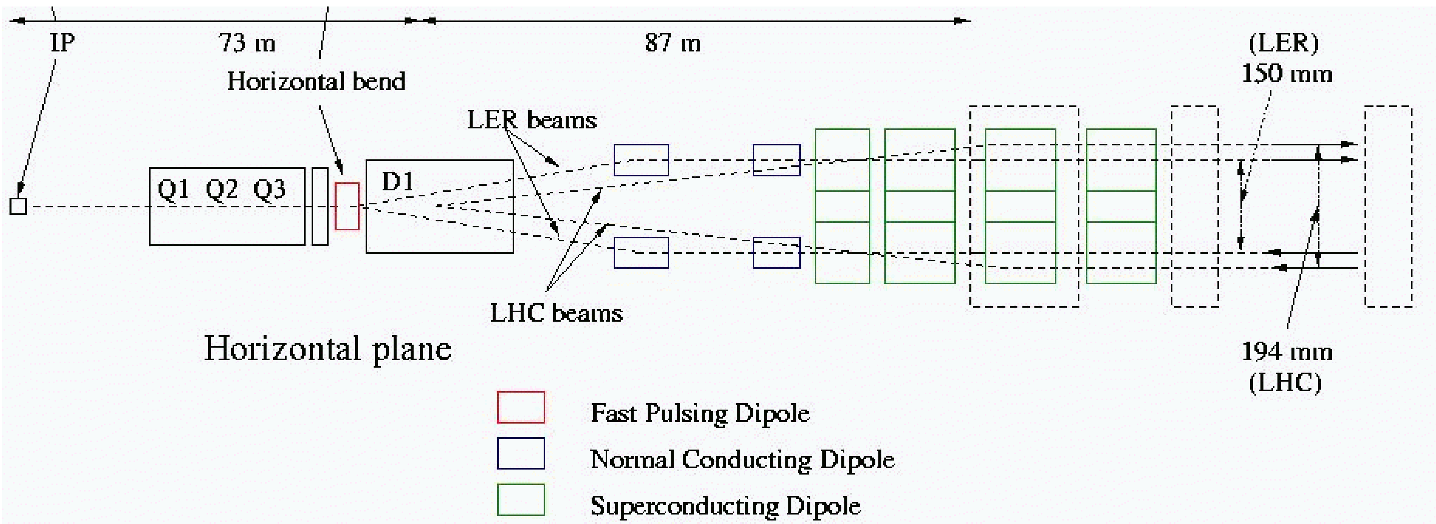


So, on to Option #2.....

LER IR1/5 TRANSFER OPTION #2

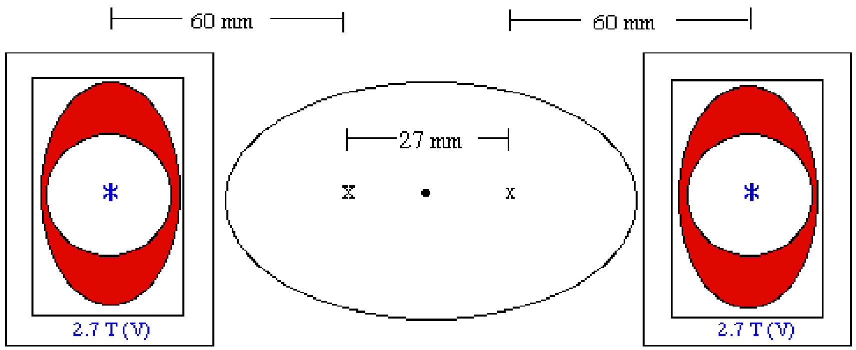
- In the Option #2 approach the aim is to separate the beams horizontally more rapidly than results from D1 alone.

- The D1 magnets slide towards D2 by ~6m to create space for installing fast, horizontal bend magnets. An integral B·dl of 8.8 T·m supplementing the D1 bending is sufficient to separate the LER beams by 140 mm at the exit of D1.



- At the outboard face of D1 unlaminated 2.7 T vertically bending magnets can be immediately installed, followed by horizontal bends to fix the horizontal separation at 150 mm, matching the arc magnets' aperture.

LER IR1/5 Option #2 (cont'd)



OUTBOARD FACE OF D1

- The great advantages to this scheme over option #1 are:

  (i) vertical bending starts much closer to the IP, making it easier to clear D2;
  (ii) only the initial separating magnets inboard of D1 need to be fast pulsed;
  (iii) the magnets outboard of D1 contain only a single beam and can therefore be much stronger than in option #1, and;
  (iv) the beams are sufficiently separated everywhere outboard of D1 that laminated magnets are not necessary (easier, cheaper design).

- However(!) It will be very difficult to acheive the necessary initial bend field if the pulsed magnets must enclose the current enormous 130 x 63 mm D1 beampipe.

FURTHER STUDIES

- For the Low Energy Ring to be a sensible idea the LER & LHC must, at the very least, share a common beampipe through the IR1 & IR5 detectors. The greatest stumbling block at this time does not appear to be in the optics design, but rather in creating the necessary separation between the 2 rings in very limited distances.

> Solutions to the Options 1 & 2 magnet difficulties **MUST** be found, and is a critical priority to enable continuing lattice design in the near future.

- For option #1 to be viable will require re-examining & re-designing the pulsed magnet concept to permit vertical bending to begin closer to D1.

- For option #2 to succeed will need imaginative re-design of the initial separating magnets in addition to evaluating possibile compromises that can diminish the size of the D1 beampipe. This examination will most fruitfully be addressed in close consultation with CERN experts.

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